

On the Discharge between Concentric Cylinders in Gases at Low Pressures.

By F. W. ASTON, B.A., B.Sc., A.I.C., Trinity College, Cambridge.

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In some previous communications* the author has described investigations upon the length of the Crookes dark space and the relation between current and potential in the discharge between large plane aluminium electrodes in different gases at various pressures.

For all the chemically active gases, and also for the gases of the helium group when these are not in a state of great purity, the two following equations were found to hold over a considerable range of the four variables :—

$$D = \frac{A}{P} + \frac{B}{\sqrt{C}}, \quad (I) \qquad V = E + \frac{F\sqrt{C}}{P}, \quad (II)$$

where D is the length of the dark space, P the pressure, V the potential difference between the electrodes, and C the current density. On examining the values of the four constants A, B, E, and F, it will be seen that although A, E, and F have widely different values for different gases the variations in the values of B (taking the cases of gases in which it was fairly constant) are very small and may be regarded as insignificant considering the difficulty of its accurate determination.

In such cases of cylindrical discharge tubes with plane electrodes filling the tubes it is clear that so long as we only consider the part of the discharge not affected by the glass wall the current density will be the same at every point along the discharge, and therefore no information can be obtained as to the particular part of the discharge upon which the value of the current factor B of the dark space depends.

If now the parallel plane electrodes are replaced by two in the form of concentric cylinders the current density will vary from point to point throughout the discharge, so that valuable information upon B and the nature of the discharge in general might be expected from accurate measurements of the values of D, C, P, and V for electrodes of this type.

The present paper contains the results obtained with the discharge between such cylinders in the gases oxygen and hydrogen.

* F. W. Aston, 'Roy. Soc. Proc.,' 1907, A, vol. 79. p. 80 ; F. W. Aston and H. E. Watson, *ibid.*, 1912, A, vol. 86, p. 168.

Apparatus.

The discharge tube is shown in section in fig. 1. The containing vessel was a glass shade, into this was pushed a cylinder of thin aluminium sheet A which just fitted it, the inside surface of this formed the outer electrode. The inner electrode was an aluminium tube B, of exactly the same length as A, whose outer surface formed the inner electrode. It was supported in an exactly concentric position with regard to A upon a glass tube passing through the neck of the shade. This system of cylinders was closed at one end by the mica sheet M, and at the other by the plate-glass disc N, which was cemented on to the ground end of the shade with sealing

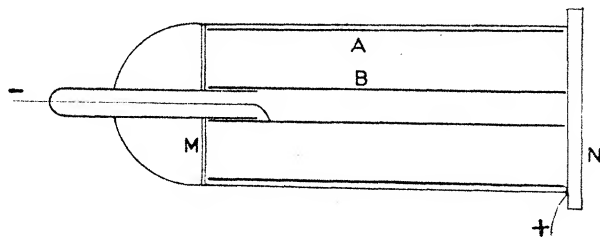


FIG. 1.

wax. By means of a side tube (not shown) the apparatus was connected to an arrangement by which gas could be admitted, and also to pumps and a liquid air charcoal tube by which the correct degree of exhaustion could be obtained.

The pressure was read on a special McLeod gauge designed by the author and capable of reading to a high degree of accuracy over the ranges employed. The current, as in the previous experiments, was derived from a large battery of small accumulators and controlled by two water resistances in parallel.

An exceedingly delicate and accurate Hartmann and Braun milliampère-meter being available, this was used to measure both the current and the potential by an arrangement of connections shown in the accompanying diagram (fig. 2), in which A is the ammeter, D the discharge tube, G a resistance equal to that of the ammeter, and R a heavy standard megohm. By rocking the connecting link of the ordinary six-pole see-saw reversing switch S, the ammeter can be made to read the current flowing through the discharge tube, or that flowing through the megohm, at will. As the whole scale of 100 divisions read 1 milliampère, the latter arrangement formed a dead-beat voltmeter reading up to a thousand volts with an accuracy of 1 volt.

By putting in a low resistance shunt *W* in the position indicated in the diagram, the range of the ammeter could be multiplied to any degree

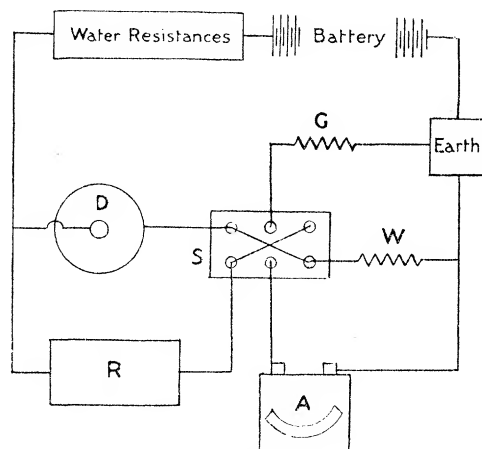


FIG. 2.

to suit the current values used without interfering with its function as a voltmeter.

The cylinders had diameters 8.20 and 1.27 cm. respectively, with a common length of 18.0 cm. Hence the effective cathode areas, *i.e.*, the inner surface area of the outer cylinder and the outer surface area of the inner cylinder were (neglecting the edge effect at the ends) 463 and 72 sq. cm. respectively, and a shunt giving 5 divisions per milliampère was generally used.

As there were no guard-ring arrangements on the electrodes the edge effect, which in this case was an end effect, was not eliminated, so that the values of the current stated are only approximate measures of the current densities.

The length of the Crookes dark space was measured by a simple sighting arrangement similar to that already described, which was mounted on a micrometer carriage giving readings to 0.05 mm.

The hydrogen and oxygen used were prepared by the electrolysis of a solution of barium hydrate and were admitted into the tube in a perfectly dry state.

The order of experiment was the same as had been found most convenient in previous work of this kind; that is to say, a series of readings of dark space and voltage for four or five definite current values (chosen to be suitable for curve plotting) were taken at constant pressure; the pressure was then altered, either by letting in fresh gas or pumping out, and another series taken.

The range of current, which is limited on the one side by the fact that it

must be considerably larger than that necessary to cover the cathode with glow, and on the other by the heat given out and the voltage at disposal, was much the same whether the inner or the outer cylinder was cathode. Owing to the disparity between their respective areas the range of current density at the cathode surface was over higher values for the inner than the outer, the two ranges barely overlapping.

Results.

The discharge, as was to be expected, resembled that between plane electrodes in its general appearance. With oxygen the edge of the dark space was absolutely sharp at all pressures, although the negative glow became faint at low pressures when the inner cylinder was used as cathode. The surface of the negative glow appeared almost perfectly cylindrical over a considerable range of dark space length whichever way the current was passing. Beyond a certain limit, however, the dark space was shorter in the middle of the tube than at the ends and the current density evidently not uniform. There is, therefore, little value in the readings of the dark space which exceed 2 to 2.5 cms.

When the length of the dark space approached the distance between the electrodes this uneven distribution of the discharge became very marked, and in the case of the outer cathode the negative glow finally appeared in the form of a bright cloud of a shuttle shape surrounding the middle of the inner cylinder.

The appearance with hydrogen was much the same as that with oxygen, except that the edge of the dark space was not nearly so well defined and almost impossible to measure at low currents.

The *primary dark space** was quite visible at low current densities and very much clearer at the outer cathode than the inner. The conditions of the experiments were not suitable for its accurate measurement.

In the four accompanying tables are given the actual readings obtained. D is expressed in centimetres, P in hundredths of a millimetre of mercury, and V in volts. The values of C are those of the total current flowing through the tube in fifths of a milliampère; for the calculation of the constants they are reduced to current densities, employing the convenient unit, previously used,† of one-tenth of a milliampère per square centimetre.

* F. W. Aston, 'Roy. Soc. Proc.,' 1907, A, vol. 80, p. 45.

† F. W. Aston, 'Roy. Soc. Proc.,' 1907, A, vol. 79, p. 80; F. W. Aston and H. E. Watson, *ibid.*, 1912, A, vol. 86, p. 168.

Table I.—Oxygen. Outer Cylinder used as Cathode.

C.	V.	D.	C.	V.	D.	V.	D.	V.	D.
50	363	1·285	25	342	1·715	350	1·800	342	1·860
75	369	1·125	44½	350	1·415	360	1·480	350	1·505
100	374	1·010	64	356	1·260	370	1·290	360	1·330
150	384	0·880	100	365	1·055	380	1·125	373	1·145
P = 14·0 A = 4·2			P = 8·5 A = 3·0			P = 6·65 A = 2·7		P = 5·66 A = 2·7	
C.	V.	D.	V.	D.	V.	D.			
25	357	1·920	365	2·005	405	2·220			
44½	367	1·590	373	1·640	416	1·890			
64	378	1·405	385	1·460	430	1·720			
100	385	1·220	402	1·290	459	1·490			
P = 5·06 A = 2·7			P = 4·25 A = 2·6			P = 3·08 A = 2·6			

Table II.—Oxygen. Inner Cylinder used as Cathode.

C.	V.	D.	V.	D.	V.	D.
16	368	1·200	405	1·420	425	1·550
25	390	1·050	438	1·255	465	1·370
44 $\frac{1}{2}$	427	0·900	496	1·120	532	1·230
64	460	0·830	543	1·045	589	1·170
100	510	0·770	615	0·975	670	1·110
P = 16·80 A = 7·5 F = 24			P = 10·80 A = 7·5 F = 22		P = 9·27 A = 7·5 F = 22	
C.	V.	D.	V.	D.	V.	D.
16	461	1·725	560	2·335	611	2·760
25	509	1·580	686	2·070	670	2·380
44 $\frac{1}{2}$	590	1·410	711	1·850	765	2·090
64	650	1·340	790	1·770	848	1·970
100	748	1·270	916	1·705		
P = 7·40 A = 7·4 F = 21			P = 4·98		P = 4·19	

Table III.—Hydrogen. Outer Cylinder used as Cathode.

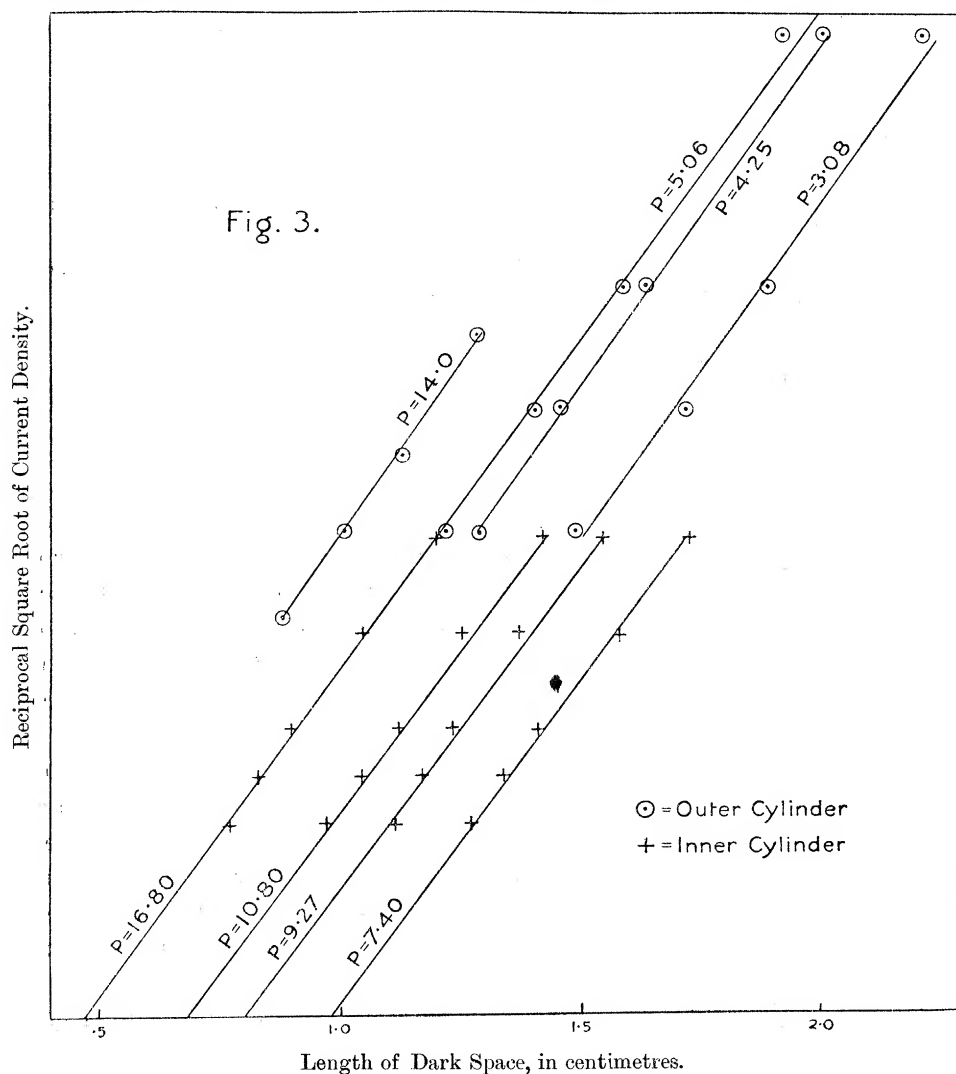
C.	V.	D.	V.	D.	V.	D.	V.	D.
25	—	—	240	2·230	250	2·340	—	—
44½	240	1·705	259	1·875	277	1·970	317	2·140
64	250	1·450	273	1·650	298	1·750	347	1·990
100	268	1·340	297	1·470	328	1·545	390	1·655
150	288	1·190	321	1·300	361	1·350	436	1·490
		P = 35·8 A = 21·6 F = 47·7			P = 24·2 A = 17·7 F = 40·3			P = 17·6 A = 13·0 F = 40·6
								P = 11·6 A = 11·0 F = 38·0

Table IV.—Hydrogen. Inner Cylinder used as Cathode.

C.	V.	D.	V.	D.	V.	D.	V.	D.	V.	D.
25	—	—	362	1·750	390	1·930	411	2·025	470	2·460
44½	330	1·180	430	1·610	467	1·800	499	1·870	576	2·180
64	363	1·130	482	1·515	527	1·730	565	1·770	658	2·060
100	422	1·050	422	1·050	614	1·600	662	1·705	780	1·920
150	470	0·980	636	1·330	708	1·520	—	—	—	—
	P = 47·4 A = 32 F = 68		P = 27·2 A = 30 F = 61		P = 22·3 A = 29 F = 58		P = 19·4 A = 29 F = 56		P = 15·3 A = 29 F = 55	

when the current was reversed was far greater than might be expected from considerations of cathode area only. Such a discharge tube is, in effect, an electric valve and, properly designed, might form an efficient rectifier, since the restriction of the volume of the negative glow caused by the use of the outer cylinder as cathode seemed to help rather than hinder the passage of the current.

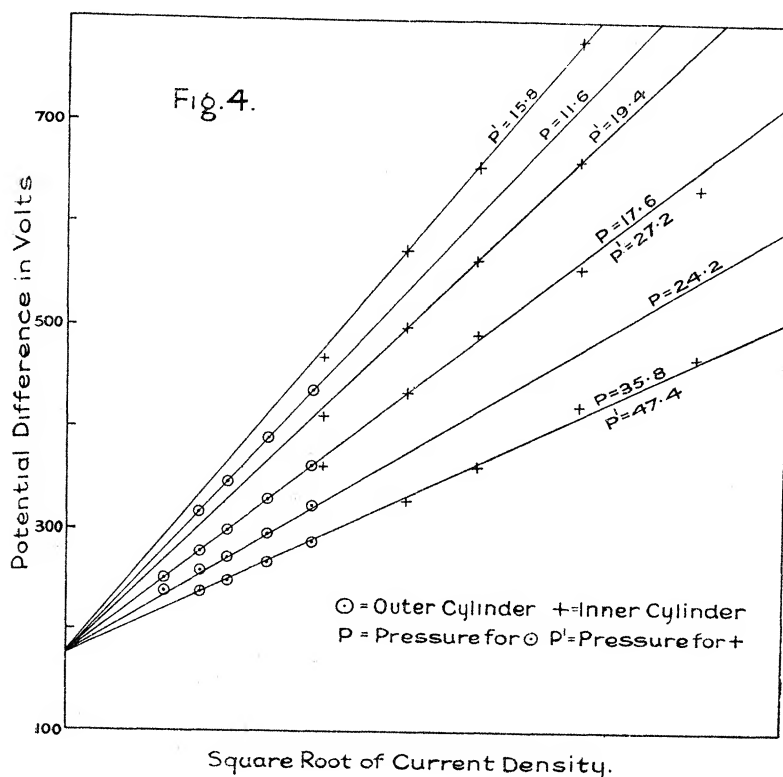
The most important relation, to determine which these experiments were primarily undertaken, is that connecting dark space length with pressure and current. On the accompanying diagram (fig. 3) are plotted some of the results for oxygen. It was soon evident that the slopes of the lines, *i.e.*, the



values of B , were practically identical with each other whichever cylinder was used as cathode, and also equal to B already determined for plane cathodes *provided that the current in each case is expressed as current density at the surface of the cathode*. This very important result seems to indicate that whatever may be the explanation of the shrinkage of the dark space with increase of current density, the mechanism which causes it is probably at or very near the surface of the cathode.

The pressure factor A is, in oxygen, practically constant for the convex cathode, and also for the concave one at low pressure. It is much larger in the first case than in the second, the value for plane electrodes lying between the two. As B is the same for all, it follows that the effect of curvature of the cathode on the length of the dark space is exactly like a change in the pressure, an increase if it is concave, and a decrease if it is convex.

Hydrogen yields results of a similar nature, only, as this gas does not give so sharp a dark space edge, they are not so accurate. In this gas the difference between the values of A for the two cylinders is not so large,



neither—in the case of the outer cylinder—is A so constant, but shows a tendency to decrease with decrease of pressure.

Fig. 4 shows the relations between current density and voltage for hydrogen, in which it will be seen that both concave and convex cathodes obey equation (II) with fair exactness, E being the same for both. F is higher for the inner than the outer cylinder, and in both cases tends to decrease with decrease of pressure.

Similar straight lines are given by the inner cathode in oxygen.

The following are the mean values of the constants for the three forms of aluminium cathodes:—

Gas.....	A.		B.		E.		F $\times 10^{-2}$.	
	H.	O.	H.	O.	H.	O.	H.	O.
Convex	30	7.5	0.50	0.47	175	270	60	22
Plane	26	5.7	0.43	0.49	170	290	57	17.6
Concave	—	2.7	0.50	0.47	175	—	40	—

Our present knowledge of the mechanism of the dark space is inadequate to give any explanation of these figures. As its length seems to depend on the density of the ionisation within it, one might expect it to be greater for convex than for concave surfaces, since the cathode rays are divergent in the former case and convergent in the latter.

Further information on this point might be gained by the use of cylinders of various diameters. In view, however, of the apparent dependence of the constant B upon the current density at the surface of the cathode only, it seemed to the author more important that observations should be commenced upon the influence of the material of the cathode upon this and other phenomena of the discharge.

Summary of Results.

1. The relations between pressure, voltage, and the length of the Crookes dark space in the discharge between concentric cylinders take much the same form as those in the discharge between parallel planes.

2. Curvature of the surface of the cathode appears to have no influence upon the rate of alteration of the length of the dark space with change of current density, *so long as the latter is measured at the surface of the cathode.*

3. *Ceteris paribus*, the length of the dark space is greater for a convex cylindrical surface than a plane, and for a plane than a concave one.